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Replacement of freshwater small-size fish by formulated feed in snakehead (*Channa striata*) aquaculture: Experimental and commercial-scale pond trials, with economic analysis

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ABSTRACT

Traditional snakehead culture in Southeast Asia relies on use of small-size (trash) fish as food, an unsustainable practice. Following development of weaning methods and testing of formulated feed (FF) in laboratory experiments, we conducted feeding trials of FF vs. trash fish (TF) in experimental ponds at Can Tho University (CTU), followed by similar trials on commercial farms in two provinces in Vietnam. CTU pond trials consisted of five treatments (in triplicate), in which TF was replaced by FF in increasing percentages: 0 (control), 25, 50, 75, and 100% replacement of TF by FF (i.e., three treatments had mixed TF/FF diets). Although survival was significantly reduced in the 100% replacement treatment, and growth was significantly reduced in the 75% and 100% replacement treatments, the cost per kg of fish produced was 28–35% less in those high-replacement treatments compared to the 0% replacement treatment. On-farm trials were then conducted at two farms in An Giang and Dong Thap provinces for 6 months with snakehead fed TF only or FF only. At both farms, survival (73–80%) was not significantly different, but growth was significantly better on FF diet at both; however, FF-fed fish at the An Giang farm showed significantly higher levels of abnormal development. Overall production was about twice as high at the An Giang farm as at Dong Thap, but significantly greater production by FF-fed fish vs. TF-fed fish was only seen at Dong Thap. Sensory evaluation by a tasting panel found no difference in product quality between FF-fed fish, TF-fed fish, and a commercial sample bought in the market. Economic analysis indicated that profits were higher for FF-fed fish from both farms, although production costs and sales varied greatly, reflecting market differences in the two provinces.

1. Introduction

Snakehead culture in Vietnam and Cambodia has traditionally relied on juvenile snakehead captured from local waters, as well as small-size fish (also known as trash fish (TF) or low-value fish) as feed for the captured snakehead. Feeding cost is the biggest cost to the farmer. The most important problems associated with these practices are poor quality of trash fish and variable nutritional composition because of inappropriate storage. Risk of disease introduction, environmental pollution and high feed conversion rate (FCR) in snakehead rearing are also major concerns. In addition, the removal of snakehead and small-size fish from natural populations likely affects the fish community on which local fishers rely. Moreover, the growing competition between human and aquaculture usage of small-size fish led to increasing prices to the farmer (Rachmansyah et al., 2009). For those reasons, it is necessary to develop cost-effective and high-performing formulated feeds (FF) that would allow less reliance on small-size fish and would have lower environmental impacts. The first step in that process is the development of hatchery techniques and weaning diets for the two primary snakehead species in Vietnam, the snakehead murrel (*Channa striata*) and the giant snakehead (*Channa micropeltes*), which has been accomplished (Hien et al., submitted). The development of diets for further ongrowing of these species has also been accomplished (Hien et al., 2015a) at laboratory scale. It was recognized that snakehead previously fed on trash fish would not

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readily take a dry feed and thus development of an appropriate feed acceptable to the fish was an important aspect of our feed development work. In Vietnam, snakehead pond culture consists primarily of *C. striata*, whereas cage culture consists primarily of *C. micropeltes*. This study was designed to determine the percentage of TF that could be replaced by FF in experimental pond culture for optimum growth and survival of *C. striata* and then to compare *C. striata* production with TF vs. FF on commercial farms. The economics of production were also calculated so that farmers could see whether or not use of formulated feed would be beneficial to them financially.

2. Methods

2.1. Pond trial

Based on the results of our previous experiments (Hien et al., 2015a), we developed a 45% protein formulated feed for snakehead using fish meal (FM), soybean meal (SBM), rice bran (RB) and cassava meal (CM), with addition of the essential amino acids (EAA) methionine, threonine, and lysine and the addition of phytase (Table 1). We then set up the experimental replacement of small-size fish (SSF) diets with this formulated feed (FF) at SSF-replacement levels of 0 (control), 25, 50 75, or 100%. One experiment was conducted for *C. striata* in experimental ponds located at Can Tho University, and will therefore be referred to as the CTU pond trials. The five treatments in this experiment each had three replicates with 50 fish per replicate and were conducted in hapas. Before the start of the experiment, fingerlings had been acclimated to formulated feed for 30days.

The fish (4.7 g in initial average weight) were assigned randomly to each hapa. The experiment lasted eight weeks, during which fish were fed twice/day to satiation at 9:00 and 16:00 h. Total fish weight in each hapa was determined every 4 weeks and any dead fish were removed, recorded and weighed. After daily feedings, the remaining feed from a pre-weighed ration was weighed to determine feed intake (FI). Water temperature, measured daily, ranged from 29.5–30.5 °C. pH and dissolved oxygen, measured weekly, varied from 5.2–5.5 and 6.0–7.4 ppm, respectively.

Table 1
Formulation of the feed used in the CTU pond trials for *Channa striata*.

Ingredient	Diet composition (%)
Fish meal[a]	32.7
Soybean meal[b]	31.8
Rice bran[c]	20.0
Cassava meal[d]	7.12
Vitamin Premix[e]	1.00
Mineral Premix[f]	1.00
Fish oil[g]	3.32
Binder[h]	1.9
Lysine	0.40
Methionine	0.28
Threonine	0.41
Phytase	0.02
Total	100.00

[a] FM: KienGiang fishmeal was supplied by Minh Tam Co., Ltd. (Vietnam). Moisture: 11.7%, crude protein: 65.1%, crude lipid: 7.94%, crude fiber: 0.55% and ash:13.7%.
[b] SBM: Argentine Soybean meal was supplied by Quang Dung Co.,Ltd (Vietnam) Moisture: 8.78%, crude protein: 46.1%, crude lipid: 1.98%, crude fiber: 6.36% and Ash:6.20%.
[c] Dried rice bran was supplied by Cai Lan Oils & Fats Industries Company Ltd., Can Tho Branch, Cantho City, Vietnam. Moisture: 11.5%, crude protein12.7%, crude lipid: 14.3%, crude fiber: 5.00% and Ash: 7.94%.
[d] Cassava meal was supplied by Gentraco Fed, Cantho province, Vietnam. Moisture: 13.3%, crude protein: 2.73%, crude lipid: 2.54%, crude fiber: 2.69% and Ash: 3.12%.
[e] Vitamin mix consisted (IU kg^{1} or g kg^{1}): vitamin A: 2.500.000 IU,): vitamin D_3: 1.500.000 IU, vitamin E: 80 g, vitamin B_1: 800 mg, vitamin B_2: 2000 mg, vitamin B_6: 800 mg, vitamin B_{12}: 20 mg, vitamin C: 8 g, vitamin K_3: 1000 mg, Choline: 200 g, Niacin: 6.5 g, Folic acid: 250 mg, Biotin: 40 mg.
[f] Mineral mix consisted of $CuSO_4$: 10 g, $ZnSO_4$: 20 g, $MgSO_4$: 10 g, $CoSO_4$: 1 g, $FeSO_4$: 5 g, $MnSO_4$ 5 g, $CaHPO_4$: 1 g.
[g] Fish oil was supplied by Vemedim Company Ltd, Cantho City, Vietnam.
[h] Binder (Carboxylmethylcellulose) was (Chinese product) imported by Thanh My Company Ltd., Cantho city, Vietnam.

Table 2
The formulation of three formulated feed diets (% of dry matter basis) used in the farm trials with *Channa striata*. Diet details as described in Table 1.

Ingredients	44% CP	41% CP	38% CP
Fish meal	32.7	30.2	27.6
Soybean meal	31.8	29.3	26.9
Dried rice-bran	20.0	20.0	20.0
Cassava meal	7.12	12.0	16.8
Premix Vitamin	1.0	1.0	1.0
Premix mineral	1.0	1.0	1.0
Fish oil	3.32	3.48	3.64
Binder	1.9	1.9	1.9
Lysine	0.4	0.44	0.46
Methionine	0.28	0.28	0.28
Threonine	0.41	0.40	0.39
Phytase	0.02	0.02	0.02
Total	100	100	100
Price (USD)	0.94	0.92	0.90

Note: 1 USD = 20,600 VND.

2.2. Farm trials

Following the CTU pond trial experiment, we wanted to demonstrate the effectiveness of these diets on commercial snakehead farms. The *C. striata* farm trial experiment was carried out at two farms in An Giang and Dong Thap provinces simultaneously. At each farm the test was set up with 6 hapas (50 m^2/hapa) with a stocking density of 100 fingerlings/m^2. Hapas were placed in 2 ponds, each 500 m^2. In pond 1, snakehead fingerlings (12–13 g/fish) in the three hapas were fed marine trash fish (control treatment) for 6 months. In pond 2, snakehead fingerlings (12–13 g/fish) in the three 3 hapas were fed formulated feed. During the first two months, snakehead fingerlings were fed a diet named CTU-CRSP 1 with 44% crude protein (CP). In the third month, fish were fed diet CTU-CRSP 2 (41%CP) and in the two last months, they were fed CTU-CRSP 3 (38% CP). The formulation of three diets is given in Table 2.

Formulated feed was made from the main ingredients Kien Giang fish meal, defatted soybean meal, cassava meal, and dried rice-bran. All diets were made in an extruding pellet mill at CTU. Trash fish was marine trash fish bought from markets and was chopped up before feeding. In both CTU pond trials and farm trials, the amount of feed used daily was recorded. The following water quality parameters were measured monthly: transparency (Secchi disk), pH, dissolved oxygen, ammonia and nitrite. Growth was recorded monthly by weighing 30 fish/hapa. At the end of the experiment, a sensory evaluation, described below was also conducted to compare the fillet quality of experimental fish and wild fish.

2.3. Calculation formulas

1. Chemical composition of the experimental feeds (see below)
2. Survival rate (%) = (Number of fish end of experiment/number of initial fish) × 100
3. Weight gain (WG) (g) = Final body weight – Initial body weight
4. Daily weight gain (DWG) (g.day^{-1}) = [(Final body weight – Initial body weight)/duration of the experiment]
5. Feed Conversion Ratio (FCR)

Table 3
Proximate analysis of experimental diets (% dry matter basis) used in the farm trial with *Channa striata*. MTF refers to the marine trash fish diet against which the formulated feeds were tested.

Composition (%)	44% CP	41% CP	38% CP	MTF
Dry matter	90.0	90.5	90.3	26.4
Crude protein	44.5	41.1	38.3	59.1
Crude lipid	9.5	9.7	9.6	9.85
Nitrogen free extract	28.3	32.6	35.9	–
Crude ash	11.6	10.2	10.0	27.8
Crude Fibre	6.50	6.40	6.40	–

FCR (wet) = Feed intake (wet)/Weight gain
FCR (dry) = Feed intake (dry)/Weight gain

6 PER = (Final body weight − Initial body weight)/Protein intake
7 Abnormal (humpback) rate (%) = 100% × (Number of abnormal fish/total fish)

2.4. Chemical analysis

Feed was analyzed for chemical composition: moisture, crude protein (CP), crude lipid (CL), crude fiber (CF), nitrogen free extracts (NFE) and gross energy, according to AOAC (2000) methods. Loss on drying was used to determine moisture content; protein (N × 6.25) was determined by Kjeldahl method; lipid was determined by Soxhlet method; crude fiber was determined by acid and base hydrolysis; and gross energy was determined by bomb calorimeter. Carbohydrate-NFE = 100 − (CP + CL + CF). Fish samples collected at the beginning and end of the experiment were also analyzed for moisture, crude protein, crude lipid, crude ash and nitrogen free extracts. Proximate analyses for the three diets plus the marine trash fish control are given in Table 3.

2.5. Sensory evaluation

At the end of the experiment, all fish were killed, filleted and washed, then they were steamed for 3 min. First, these fish were evaluated for differences in the quality of fish fillet between the control and experimental groups by a triangle test (2 identical controls and 1 experimental group for each experimental sample) (Meilgaard et al., 1999). The control sample was snakehead that was bought at the local market. The two experimental samples named 'trash-fish' and 'formulated feed' were not known to the panelists. Three samples (1 experimental and 2 control samples) were served together to nine panelists who were asked to identify the odd sample (one out of three samples). If less than 6 out of 9 detected the odd sample correctly, we determined that there was no significant difference and therefore no need to conduct a sensory test. A paired test (Meilgaard et al., 1999) was run to determine if there was any difference in sensory attributes even if they were minor. On the other hand, if 7 out of 9 people detected the odd sample correctly, there was a significant difference at $P < 0.01$ or 6 out of 9 $P < 0.05$. In this case, a comprehensive pair test was done on appearance, texture and taste for intensity and liking (1–9 points). The intensity scale was applied to whiteness (1 dark – 5 medium – 9 very white) and structural integrity (uniformity: 1 very irregular – 5 medium – 9 very uniform) while the hedonic scale was given to overall appearance (1 least like – 5 o.k. – 9 like very much), taste (1 least like – 5, o.k. – 9, like very much) and snakehead-like taste (1, very little – 5, o.k. – 9, very much). The panel was also asked to note the presence of objectionable taste (yes or no) and the presence of objectionable odor (yes or no). Texture evaluation included the overall texture (1, least like – 5, o.k. – 9, like very much), firmness (1, very soft – 5, medium – 9, very firm), moistness (1, very dry – 5, medium – 9, very moist); chewiness (1, mushy – 5, medium – 9, very chewy), and flakiness(1, least – 5, medium – 9, very flaky). Mean values of results in different treatments were compared by paired sample *t*-test using SPSS 13.0 software. Treatment effects were considered significantly different at $P < 0.05$.

2.6. Statistical analysis

Data were checked for normal distribution by One-Sample Kolmogorov-Smirnov test and homogeneity of variances by Levene's test. Data were analyzed using One-way analysis of variance (One-way ANOVA) test followed by a Duncan's Multiple Range Test. Differences in growth and feed efficiency between diet treatments were considered to be statistically significant when $p \leq 0.05$. The statistical tests were performed using the SPSS statistical package (ver. 16.0, SPSS Company, Chicago, IL, USA).

2.7. Economic analysis

Total costs and net profits of feeding trial were calculated as follows:
Feed cost/kg fish = Feed cost/kg feed × FCR
Total costs = Feed cost + fingerling cost + labor + other costs
Profit (USD) = Total income − total cost
Profit ratio (%) = 100 × (profit/total cost)

3. Results

3.1. CTU pond trials

Survival rate of *C. striata* in the 100% FF treatment (complete replacement of trash fish by formulated feed) was 73.3%, significantly lower than all other treatments, which had very high survival rates, 95.3–92.7% (Table 4). There was a trend of reducing growth response with increased replacement by FF and fish fed diets consisting of 0% FF, 25% FF and 50% FF exhibited significantly higher final weight and daily weight gain than did fish in the 75% FF and 100% FF treatments (Table 4). FI and FCR were significantly reduced at each increasing level of FF replacement, but no significant differences were seen in PER (Table 4). Feed cost per kilogram weight gain decreased with increasing formulated feed in diets (Table 4), with a reduction up to 35.5% using 100% FF compared to the trash fish diet (0% FF). The aforementioned growth performance and survival rate of snakehead were not significantly different when 50% of trash fish was replaced by formulated feed. At this replacement proportion,

Table 4
Channa striata in the CTU pond trials: initial (Wi) and final (Wf) body weights (g), daily weight gain (DWG in g day^{-1}) and survival rate (SR in%), feed intake (FI in g fish^{-1} day^{-1}), feed conversion ratio (FCR), and protein efficiency ratio (PER), feed costs for producing one kg weight gain of in treatments where formulated fish replaced trash fish to varying degrees. Values (mean ± STD, n = 3) in the same column with the same superscript are not significantly different ($P < 0.05$).

Treatment	Wi	Wf	DWG	SR	FI	FCR	PER	Cost/kg fish (USD)	Cost reduction vs. control (%)
0 FF	4.7 ± 0.0	104.0 ± 3.9^b	1.8 ± 0.1^b	89.3 ± 0.7^b	6.69 ± 0.05^e	3.81 ± 0.18^e	1.60 ± 0.08	1.415	–
25 FF	4.7 ± 0.1	99.1 ± 1.4^b	1.7 ± 0.0^b	92.7 ± 2.4^b	4.50 ± 0.12^d	2.68 ± 0.12^d	1.74 ± 0.07	1.165	17.7
50 FF	4.7 ± 0.1	92.1 ± 5.6^b	1.6 ± 0.1^b	90.0 ± 4.2^b	3.43 ± 0.17^c	2.22 ± 0.07^c	1.66 ± 0.05	1.098	22.1
75 FF	4.7 ± 0.0	56.7 ± 5.8^a	0.9 ± 0.1^a	85.3 ± 0.7^b	1.64 ± 0.17^b	1.80 ± 0.04^b	1.65 ± 0.02	1.008	28.8
100 FF	4.7 ± 0.0	44.1 ± 5.7^a	0.7 ± 0.1^a	73.3 ± 0.7^a	0.99 ± 0.15^a	1.47 ± 0.02^a	1.68 ± 0.02	0.913	35.5

Table 5
Water quality measured in farm trials in An Giang and Dong Thap provinces.

Province	Diet	Temperature (°C)	pH	DO (ppm)	Transparency (cm)	NH_3 (mgL^{-1})	NO_2^- (mgL^{-1})
An Giang	TF	29.0–31.8	7.1–7.8	2.5–3.0	22–30	0.01–0.08	0.01–0.05
	FF	29.0–31.8	7.0–7.5	3.0–4.5	20–25	0.01–0.02	0.01–0.03
Dong Thap	TF	29.0–31.8	7.0–7.3	2.2–3.2	20–25	0.02–0.06	0.01–0.05
	FF	28.7–31.5	7.0–7.5	3.5–4.5	18–22	0.01–0.02	0.01–0.02

Table 6
Survival (SR; %), feed conversion ratio (FCR; wet and dry matter bases), protein efficiency ratio (PER; protein. weight gain^{-1}), abnormal fish (%), daily weight gain (DWG, g), production (kg) and yield (kg m^2) of *Channa striata* fed experimental diets of the farm trials in An Giang (AG) and Dong Thap (DT) provinces.

Provinces	Diets	SR	FCR (wet)	FCR (dry)	PER	Abnormal fish (%)	DWG	Production (kg)	Yield (kg/m^2)
AG	TF	74.8 ± 0.55^a	4.45 ± 0.07^b	1.12 ± 0.02^b	1.78 ± 0.03^b	1.26 ± 0.16^a	2.67 ± 0.02^a	1462 ± 8.01^a	29.2 ± 0.16^a
	FF	73.3 ± 0.32^a	1.44 ± 0.03^a	1.29 ± 0.03^a	1.56 ± 0.03^a	20.1 ± 1.83^b	2.75 ± 0.02^b	1476 ± 12.6^a	29.5 ± 0.25^a
DT	TF	78.5 ± 3.44^a	3.72 ± 0.10^b	1.10 ± 0.04^a	1.56 ± 0.06^b	00	1.15 ± 0.10^a	533 ± 30.7^a	10.7 ± 0.61^a
	FF	79.7 ± 2.67^a	1.59 ± 0.04^a	1.59 ± 0.04^b	1.34 ± 0.04^a	00	1.74 ± 0.02^b	789 ± 13.7^b	15.8 ± 0.27^b

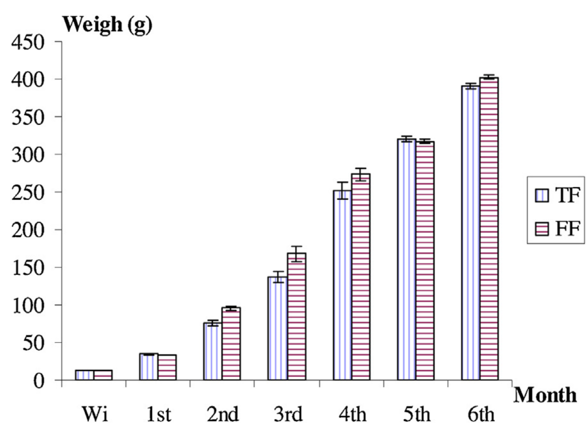

Fig. 1. Monthly growth performance of *Channa striata* during the farm trial in An Giang province.

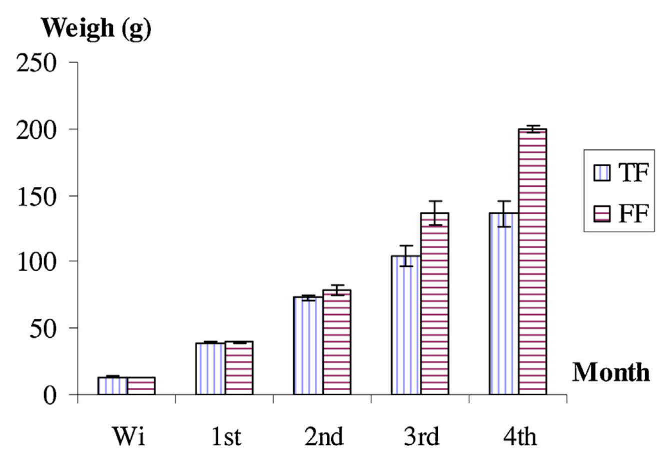

Fig. 2. Monthly growth performance of *Channa striata* during the farm trial in Dong Thap province.

the feed cost was reduced considerably by 22.1% compared to the diet containing 100% trash fish.

3.2. Farm trials

Water quality varied between the two experimental ponds in each province (Table 5). In particular, dissolved oxygen levels were lower in the ponds fed trash fish than they were in the ponds fed formulated feed.

After 6 months of culture in An Giang province, the average final weight of *C. striata* fed with formulated diet (403 ± 2 g) was significantly higher than that of fish fed with trash fish (391 ± 3 g) (Fig. 1), as was daily weight gain (2.75 ± 0.02 g day^{-1} and 2.67 ± 0.02 g day^{-1} respectively) (Table 6). After 4 months of culture in Dong Thap province, the average final weight of fish fed with trash fish (136 ± 10 g) was significantly lower than that of fish fed with formulated diet (199 ± 3 g) (Fig. 2), as was daily weight gain (1.15 ± 0.10 g/day and 1.74 ± 0.02 g/day, respectively) (Table 6).Survival showed no significant difference between fish fed formulated feed and trash fish in either of the two provinces ($p < 0.05$) (74.8 ± 0.6% and 73.3 ± 0.3%, An Giang province; 79.7 ± 2.7% and 78.5 ± 3.4%, Dong Thap province) (Table 6). Percentage of abnormally developing rate fish fed formulated diet (20.1 ± 1.83) was significantly higher than that of fish fed the trash fish diet (1.26 ± 0.16) ($p < 0.05$) in the trial at An Giang province; however, we did not observe any abnormal fish in the trial in Dong Thap province (Table 6). Abnormal development was due to lordosis or scoliosis of the vertebral column. FCR on a wet matter basis from treatment fed trash fish showed significantly higher values (4.45 ± 0.07 in An Giang province and 3.72 ± 0.10 in Dong Thap province) than did the treatments fed formulated feed (1.44 ± 0.03 in An Giang province and 1.59 ± 0.04 in Dong Thap province). However, calculating on a dry matter basis, FCR of trash fish diet was significantly lower (1.12 ± 0.02 in An Giang province and 1.10 ± 0.04 in Dong Thap province) than that of formulated feed (1.29 ± 0.03 in An Giang province and 1.59 ± 0.04 in Dong Thap province) in both provinces (Table 6). (It should be noted, though, that trash fish is purchased on a wet matter basis, not on a dry matter basis.) In addition, PER from the treatment fed trash fish showed significantly higher values than did the treatment fed formulated feed ($p < 0.05$) (1.78 ± 0.03 and 1.56 ± 0.03, An Giang province; 1.56 ± 0.06 and 1.34 ± 0.04, Dong Thap province) (Table 6). However, the daily weight gain of the fish fed formulated feed was significantly higher than that of fish fed trash fish (2.75 ± 0.02 and 2.67 ± 0.02, An Giang province; 1.74 ± 0.02 and 1.15 ± 0.10, Dong Thap province).

3.3. Economic analysis

Production did not differ significantly between ponds fed formulated feed or trash fish for snakehead culture in An Giang province, but in Dong Thap province production was significantly higher in ponds fed formulated feed than in ponds fed trash fish (Table 7).

Because the crop cycle was six months in An Giang province and only four months in Dong Thap province, both total cost and total income were higher in An Giang. Profit from ponds fed trash fish were significantly lower than that from ponds fed formulated feed in both provinces (Table 7). The feed cost made up the biggest

Table 7
Economics of experimental snakehead culture in An Giang and Dong Thap province on a per-hapa basis. Note: Crop duration was 6 months for An Giang province and 4 months for Dong Thap province. Values (mean ± SE) within a column within a province that share the same letter are not significantly different from each other.

Province	Diet	Total cost (USD/hapa)	Total income (USD/hapa)	Profit (USD/hapa)
An Giang	TF	694 ± 6.31[b]	1000 ± 5.34[a]	309 ± 10.2[a]
	FF	650 ± 6.80[a]	1009 ± 8.74[a]	361 ± 15.5[b]
Dong Thap	TF	290 ± 7.77[a]	558 ± 3.20[a]	269 ± 24.8[a]
	FF	439 ± 7.77[b]	825 ± 1.45[b]	389 ± 18.5[b]

TF: trash fish; FF: formulated feed.

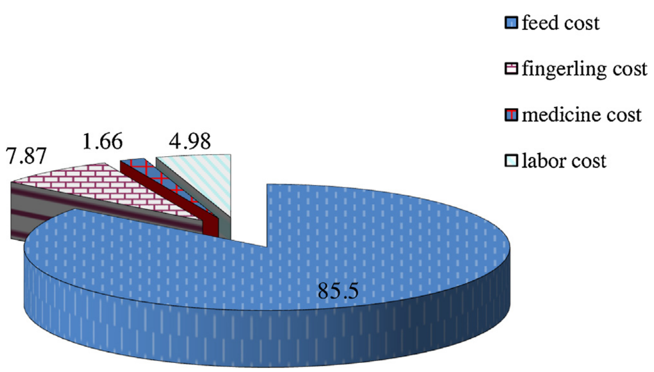

Fig. 3. Breakdown of variable costs as percentages of total cost for the ponds fed formulated feed in the farm trials with *Channa striata*.

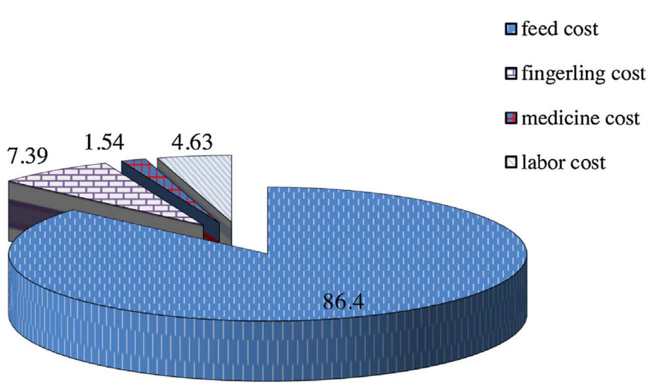

Fig. 4. Breakdown of variable costs as percentages of total cost for the ponds fed trash fish in the farm trials with *Channa striata*.

variable cost for snakehead culture in these trials, whereas costs of labor, fingerlings and chemicals were relatively minor (Figs. 3, 4).

3.4. Sensory analysis

In appearance, both fish fed trash-fish and formulated feed received scores of approximately 4–5 (Table 8), meaning that the fillets were passable or fairly likable and medium white for whiteness. On the other hand, structural integrity of fillet scored nearly 7, being relatively uniform. As for taste, the fish fillet had snakehead-like taste without the presence of objectionable taste and odor. Texture liking scored from 5 to 6, being o.k. For firmness, the scores were 4–5, being slightly soft to medium fish fillet. The fillet moistness was judged to be slightly dry to medium moist. The fillet was moderately chewy and less flaky. Differences between samples in triangle tests (less than 6 out of 9 people detected the odd sample correctly) were not significant (TF = 2.67 ± 0.33; FF = 4.33 ± 0.33). When these samples were subjected to paired tests, the quality of the fish fillet samples from the two treatments, trash-fish or formulated feed, did not differ significantly.

Table 8
Channa striata sensory analysis. Data are mean ± SE.

Content	Scores TF	FF
Appearance		
Overall appearance	4.70 ± 0.07	4.96 ± 0.13
Whiteness	4.59 ± 0.07	4.48 ± 0.04
Structural integrity	7.00 ± 0.00	6.93 ± 0.07
Taste		
Overall taste	4.30 ± 0.10	4.70 ± 0.10
Snakehead-like taste	4.56 ± 0.11	5.81 ± 0.23
Presence of objectionable taste	No	No
Presence of objectionable odor	No	No
Texture		
Overall texture	5.30 ± 0.10	5.89 ± 0.19
Firmness	5.41 ± 0.07	4.93 ± 0.10
Moistness	3.74 ± 0.07	5.04 ± 0.36
Chewiness	5.63 ± 0.04	5.67 ± 0.06
Flakiness	3.70 ± 0.07	4.04 ± 0.13

4. Discussion

The results of this study have the capability to change production methods for snakehead (*C. striata*) pond culture in Vietnam, and perhaps elsewhere in Southeast Asia. The demonstration that *C. striata* perform well in grow-out ponds when fed formulated feed, that water quality in terms of dissolved oxygen is improved, and that sensory quality of the product is not changed, in combination with the associated increased profits, could reduce the amount of small-size (trash) fish taken from the Mekong River (or marine sources) for use in snakehead culture. Hien et al. (2015b) have shown that such small-size freshwater fish actually contain the juveniles of many species of commercially important fishery species. Thus, both commercial fisheries and commercial aquaculture will likely benefit from reduced use of small-size fish. Following widespread dissemination of our experimental results to snakehead farmers in Vietnam, we estimate that over 1000 farmers have now changed their production methods from feeding TF to FF in pond culture of *C. striata*. Snakehead culture has been banned since 2005 in Cambodia because of the withdrawal of both snakehead juveniles and small-size fish to feed them from Cambodian waters. We are currently working with Cambodian scientists to transfer technology for improved snakehead production using FF, so that the ban might be lifted. It is noteworthy that the FF diets that we have developed contain a substantial amount of plant material, thereby also reducing the use of fish meal.

Utilization of commercial pellet feed is now popular, especially for carnivorous fish, in order to reduce the dependence on trash fish, feeding cost and environmental impact. Studies on replacement of trash fish by formulated feed in several species demonstrated better growth rates and more profit, such as tiger grouper, *Epinephelus fuscoguttatus* (Rachmansyah et al., 2009); Japanese sea bass, *Lateolabrax japonicus* and red drum, *Sciaenops ocellata* (Cremer et al., 2001a,b); and Asian seabass, *Lates calcarifer* (Aquacop et al., 1989). Cremer et al. (2001a,b) replaced trash fish with formulated diets in cage culture of red drum (*Sciaenops ocellata*) and Japanese sea bass *Lateolabrax japonicus*) and concluded that fish consuming formulated diet (43% crude protein, 12% lipid) with 35% soybean meal showed better growth and less feeding cost than fish fed trash fish. Replacing trash fish by formulated feed brought more benefits in feeding cost and less dependence on trash fish supply in Singapore (Aquacop et al., 1989); Asian sea bass (*Lates calcarifer*) could use formulated feed (45% crude protein) in fingerling stages but required high levels of fishmeal quality. Grouper (*Epinephelus fuscoguttatus*), a carnivorous species which requires a high protein content (445-50%) in diet, fed a mixed diet of formulated feed and trash fish with the ratio 1:1, performed insignificantly differently from fish fed trash fish completely (Rachmansyah et al., 2009).

Future research on formulated feed for *C. striata* should focus on the elimination of abnormalities in fish fed the formulated feed. The lordosis and scoliosis seen in fish in the farm trial in An Giang province is a classic sign of vitamin C deficiency (Halver, 2002). Thus, studies of the dietary requirement of *C. striata* for vitamin C, as well as the use stable forms of vitamin C in snakehead diets, should be conducted.

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